P5 Presentation: LSST

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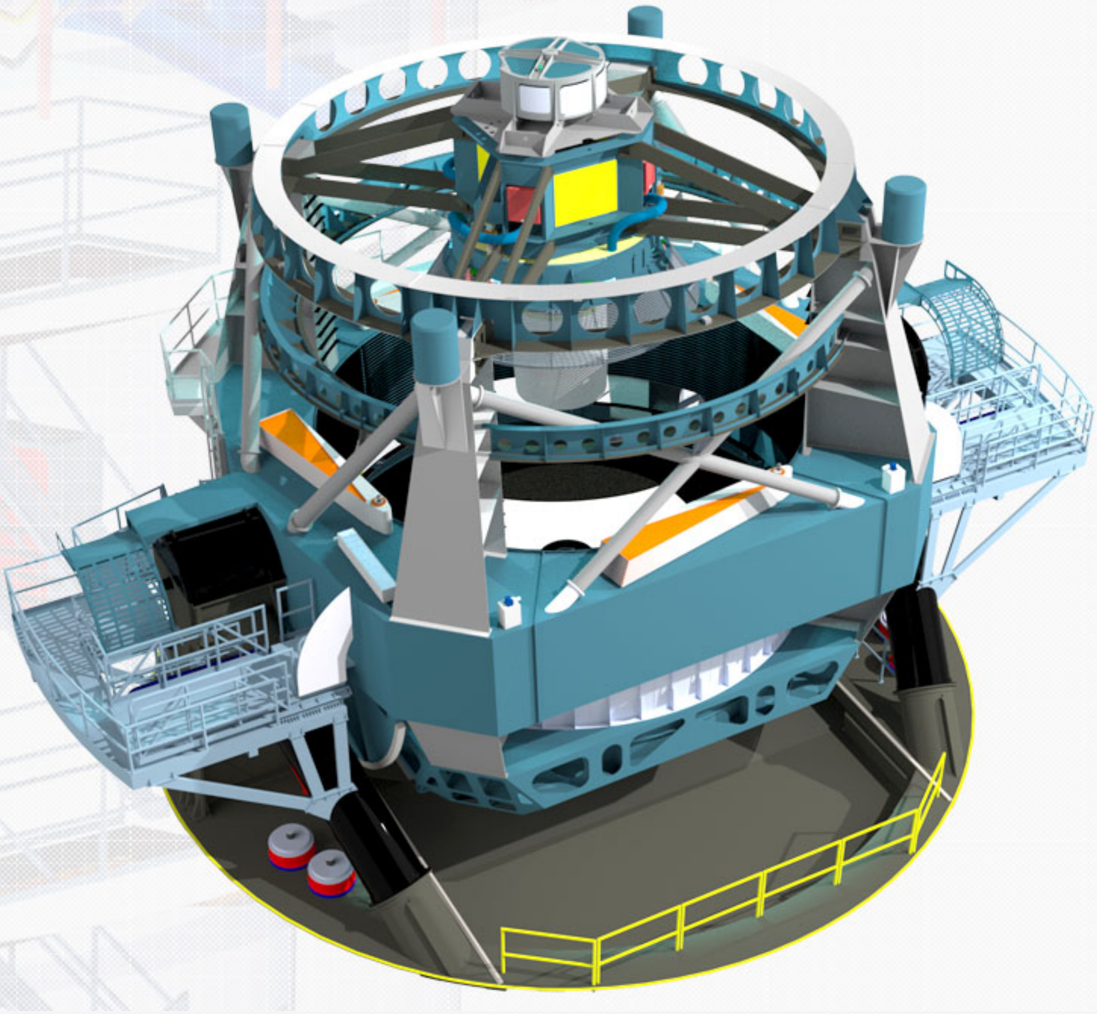
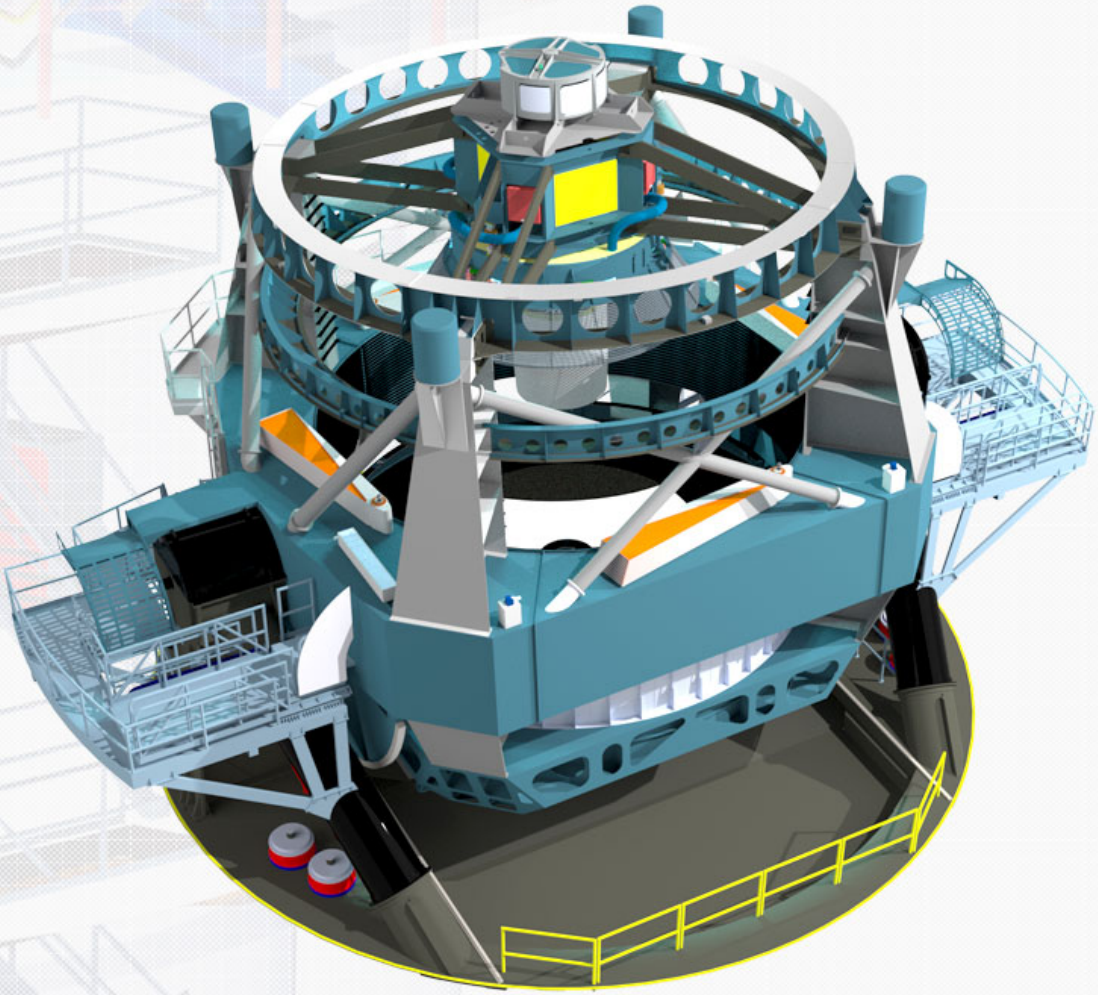


Outline

- Telescope and Survey
- Probes of dark energy and gravity
- The path to first light

Telescope and Survey



LSST in a Nutshell

- The LSST is designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.

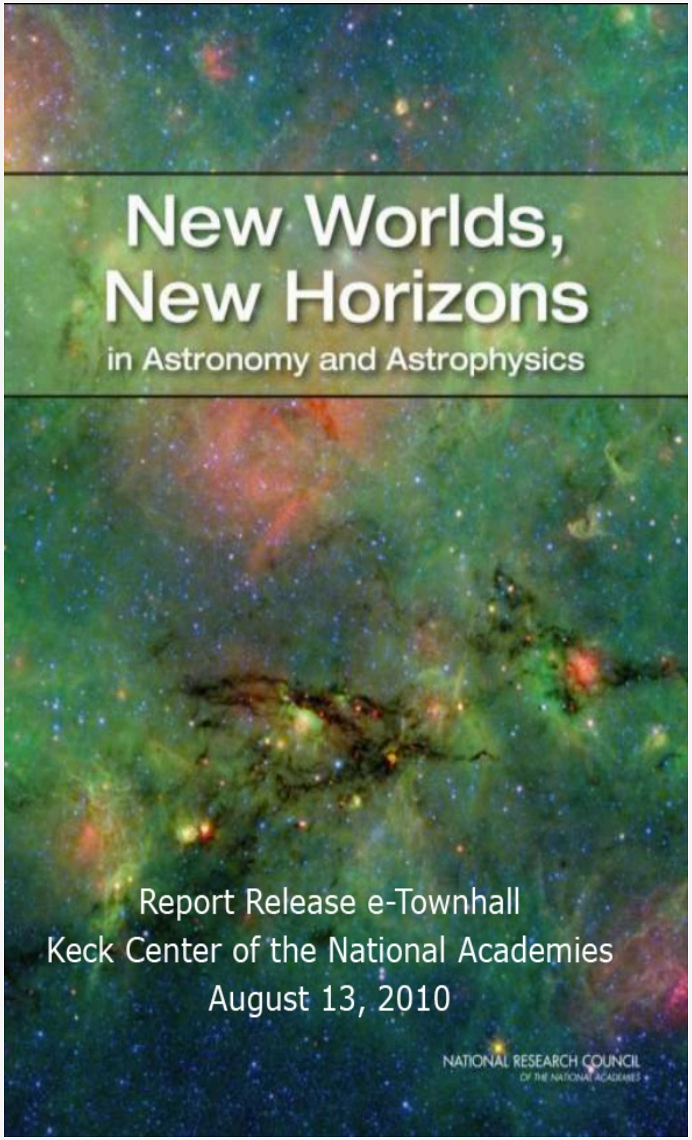
- The LSST survey over the Southern sky will image 4 billion galaxies and 100,000 Supernovae for cosmological studies.

- LSST will meet the requirements for a Stage IV dark energy survey. More generally, it will be the ``ultimate'' ground-based imaging and time-domain survey.
  - For cosmology it will enable measurements with five well known probes of dark energy as well as we can carry them out from the ground.
  - Its broad scope ensures that it will enable a suite of new tests of dark energy, dark matter and gravity.

Astro2010 Endorsement

- LSST ranked as the highest priority large ground-based facility for the next decade.

- “The top rank accorded to LSST is a result of (1) its compelling science case and capacity to address so many of the science goals of this survey and (2) its readiness for submission to the MREFC process as informed by its technical maturity, the survey’s assessment of risk, and appraised construction and operations costs. Having made considerable progress in terms of its readiness since the 2001 survey, the committee judged that LSST was the most ‘ready-to-go.’”



LSST is a Public/Private, Interagency Project

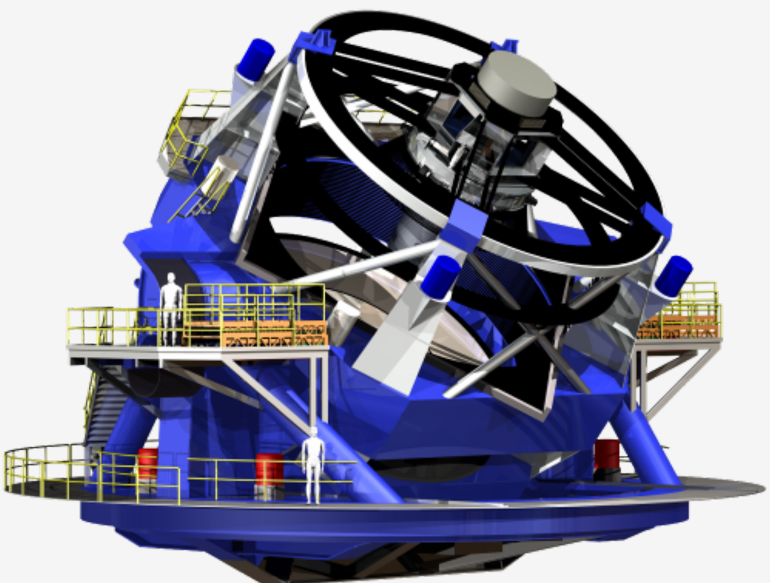
- The National Science Foundation:
  - Support for the telescope and site facility construction, the data management system, and the education and public outreach components.
  - Funded under the Major Research Equipment and Facility Construction (MREFC) line. Total projected cost is $488M.
  - Prime contractor for this effort is the Associated Universities for Research in Astronomy (AURA), which also manages the National Optical Astronomy Observatory (NOAO), the Space Telescope Science Institute (STScI), and other facilities.
- The Department of Energy:
  - Support for the camera fabrication.
  - Funded as a Major Item of Equipment (MIE), through the Office of High Energy Physics in the Office of Science. Total projected cost is $165M.
  - SLAC National Accelerator Laboratory is the lead DOE lab for the LSSTcam project.
- Private Support:
  - Total Support is ~ $40M.
  - Funded development of the primary/tertiary mirror, the secondary mirror blank, preliminary site preparation, as well as early sensor studies and some data management activities.
  - Responsible organization is the Large Synoptic Survey Telescope Corporation.

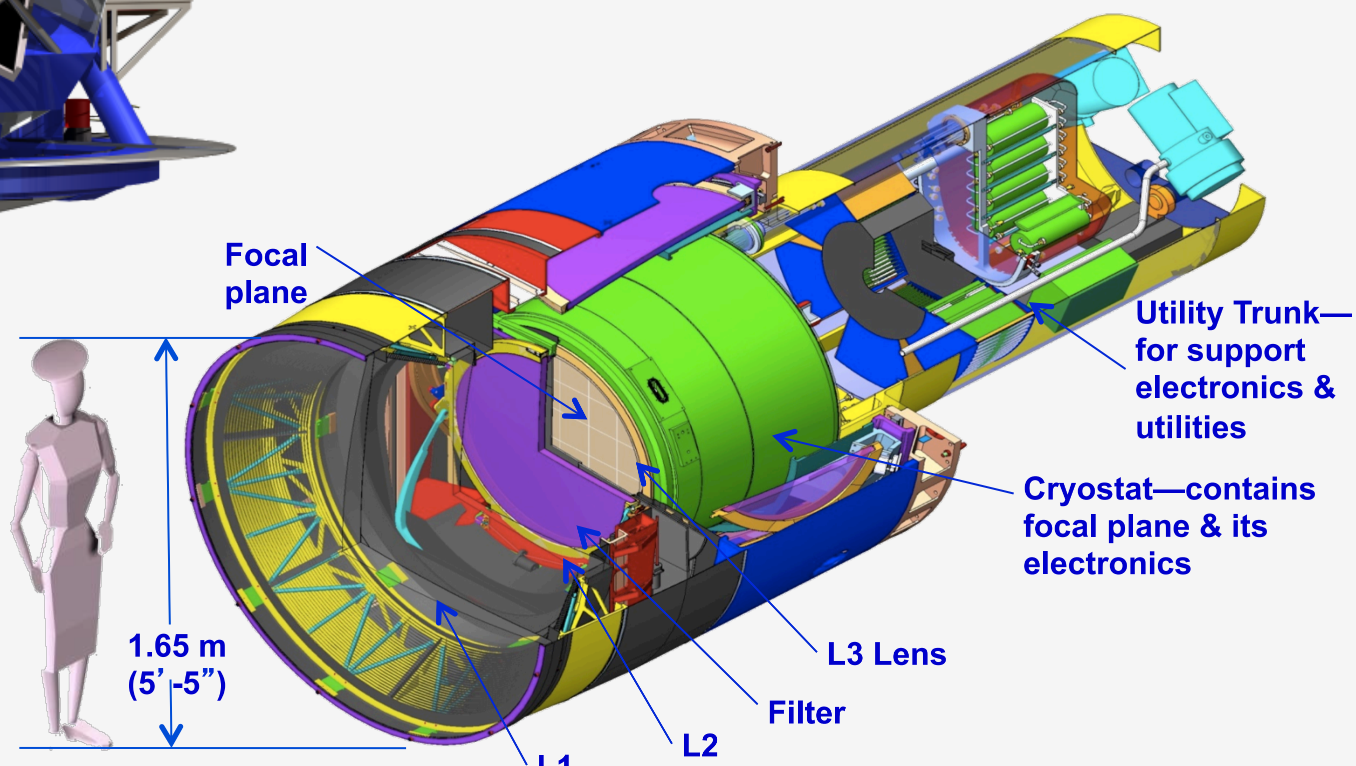
Four Key Science Themes Used to Define the Science Requirements

- Taking a census of moving objects in the solar system.
- Mapping the structure and evolution of the Milky Way.
- Exploring the transient optical sky.
- Determining the nature of dark energy and dark matter.

The techniques associated with these four themes stress the system design in complementary ways. By designing the system to to accomplish these specific goals, we ensure that LSST will in fact enable a very broad range of science.

8m telescope + 3 Billion Pixel Camera

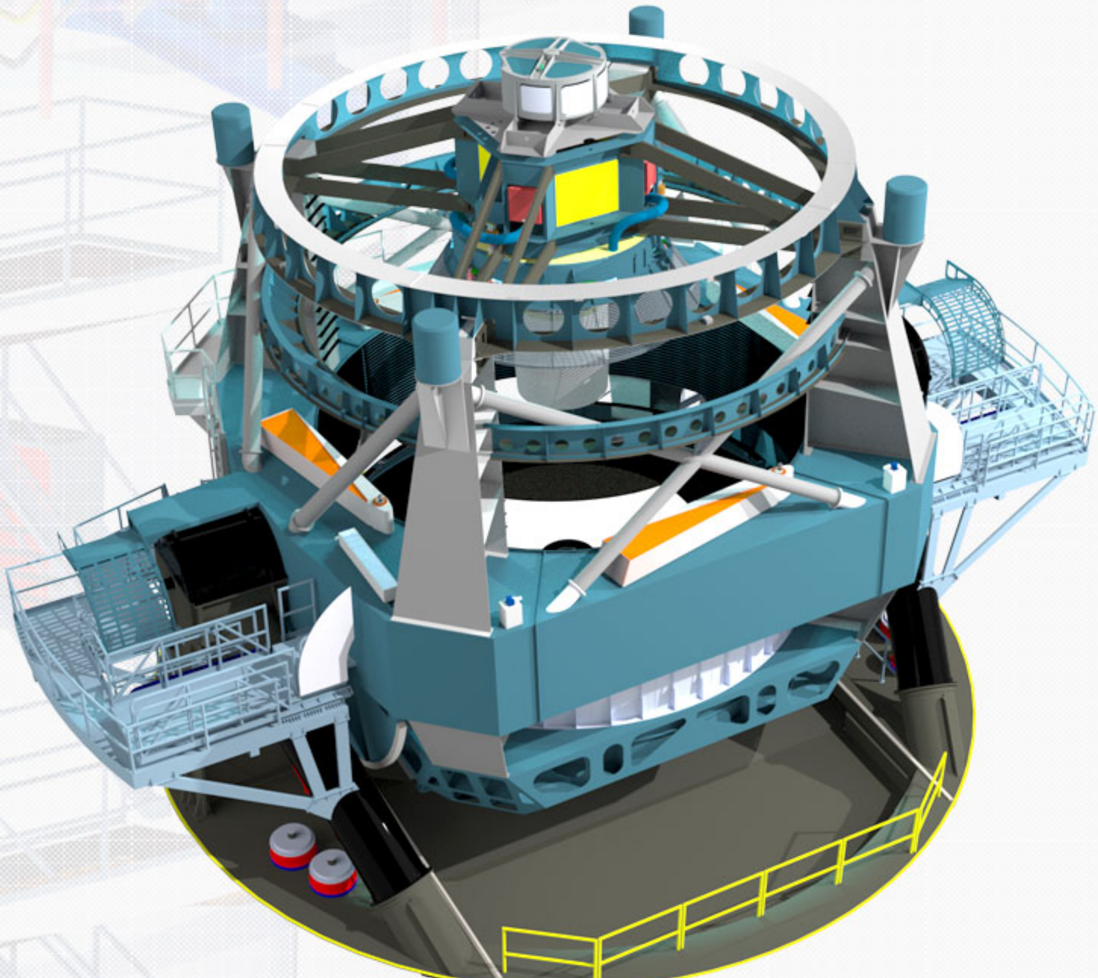




Summary of High Level Requirements

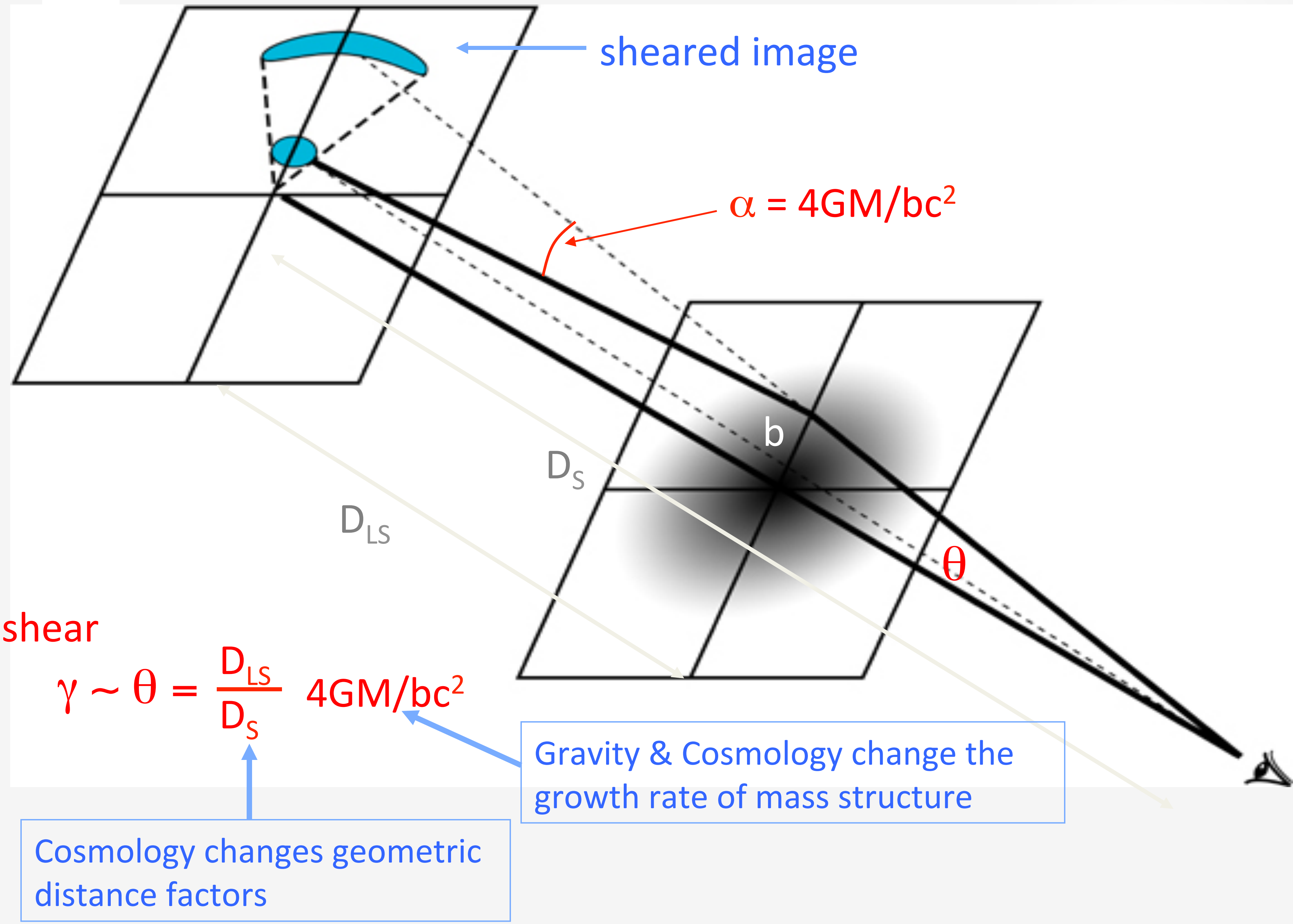
Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute, 0.5% repeatability & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	60 sec after last visit exposure
Data release	Full reprocessing of survey data annually

Probes of dark energy and gravity

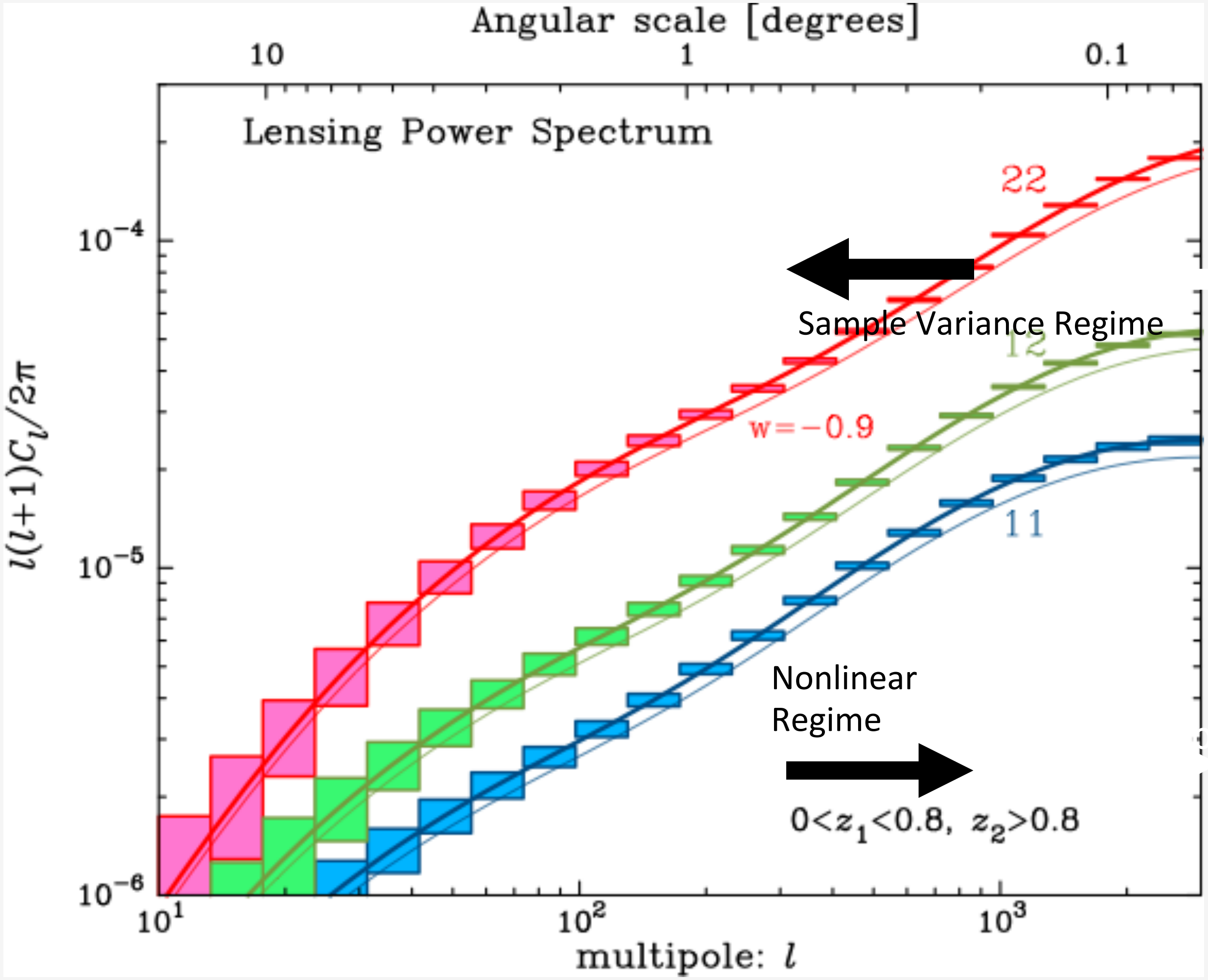


Dark Energy Probes with LSST

Probe	Physical Observable	Sensitivity to Dark Energy or Modified Gravity
Weak Lensing	Coherent distortions in galaxy shapes	Geometry and growth of structure (projected)
Large-Scale Structure (BAO)	Power spectrum of galaxy distribution	Distance-redshift relation
Galaxy Clusters	Abundance of massive clusters	Growth of structure and geometry
Type Ia Supernovae	Fluxes of standard candles	Distance-redshift relation
Strong Lensing	Time delays of multiply lensed sources	Distance-redshift relation


sheared image
α = 4GM/bc²
b
D_S
D_LS
θ
shear
γ ~ θ = (D_LS / D_S) 4GM/bc²
Gravity & Cosmology change the growth rate of mass structure
Cosmology changes geometric distance factors

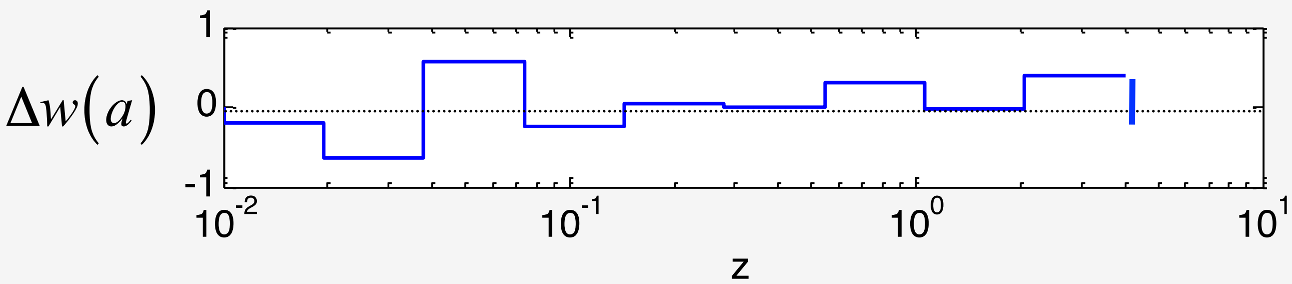
LSST Cosmic Shear power spectra



- Dark energy signature: relative amplitudes of the different spectra.
- 18,000 sq. deg; 30 galaxies/sq. arcmin. Statistical errors + Equal contribution from systematics.
- LSST will makes an order of magnitude advance in WL as well as Clusters, LSS and SN.

Beyond Dark Energy

- Is dark energy constant in redshift?

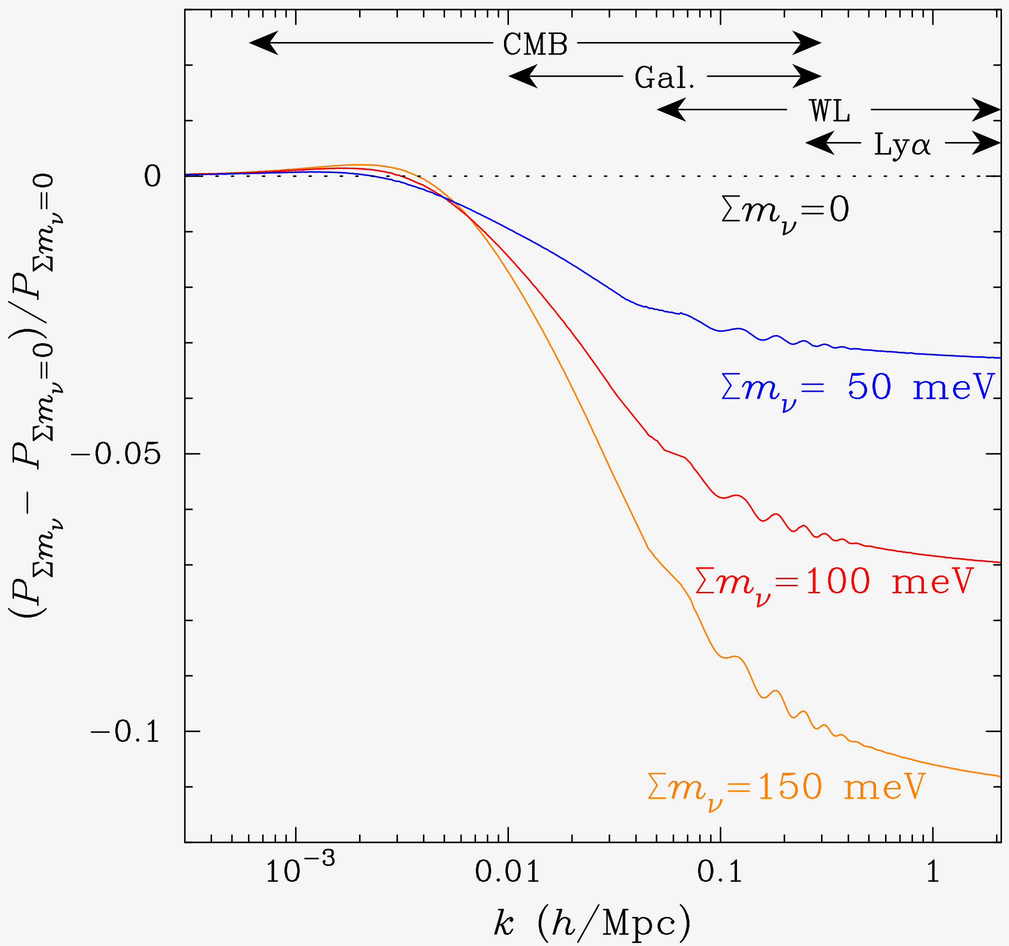


- Is dark energy spatially clustered or anisotropic?
- Are there couplings between dark energy, dark matter, baryons?
- Is it dark energy or modified gravity?

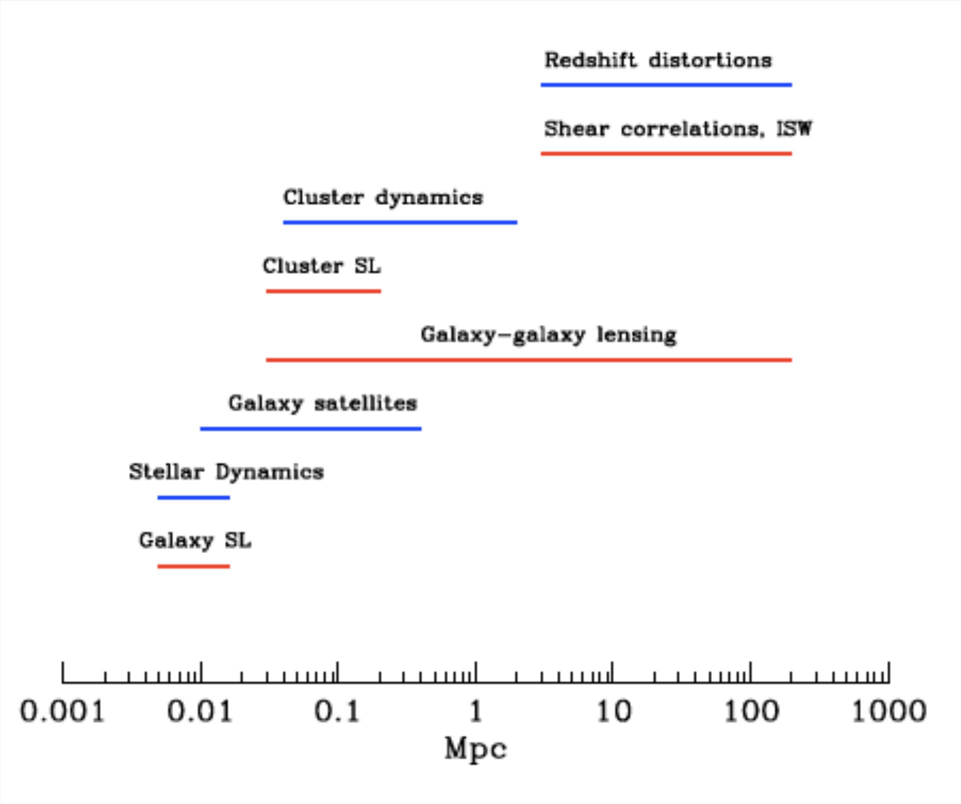
LSST is designed to address each of these possibilities by (a) using its spatial and time-domain data, and, (b) combining its measurements with complementary cosmological surveys.

Multi-component dark matter and neutrinos

- Neutrinos as a known hot component of dark matter
- Suppress growth of structure in a scale dependent way
- LSST constraints will be competitive with other cosmological probes
- Note: LSST power spectra are 2d, projected spectra. Also sensitive to other features in the primordial power spectrum.

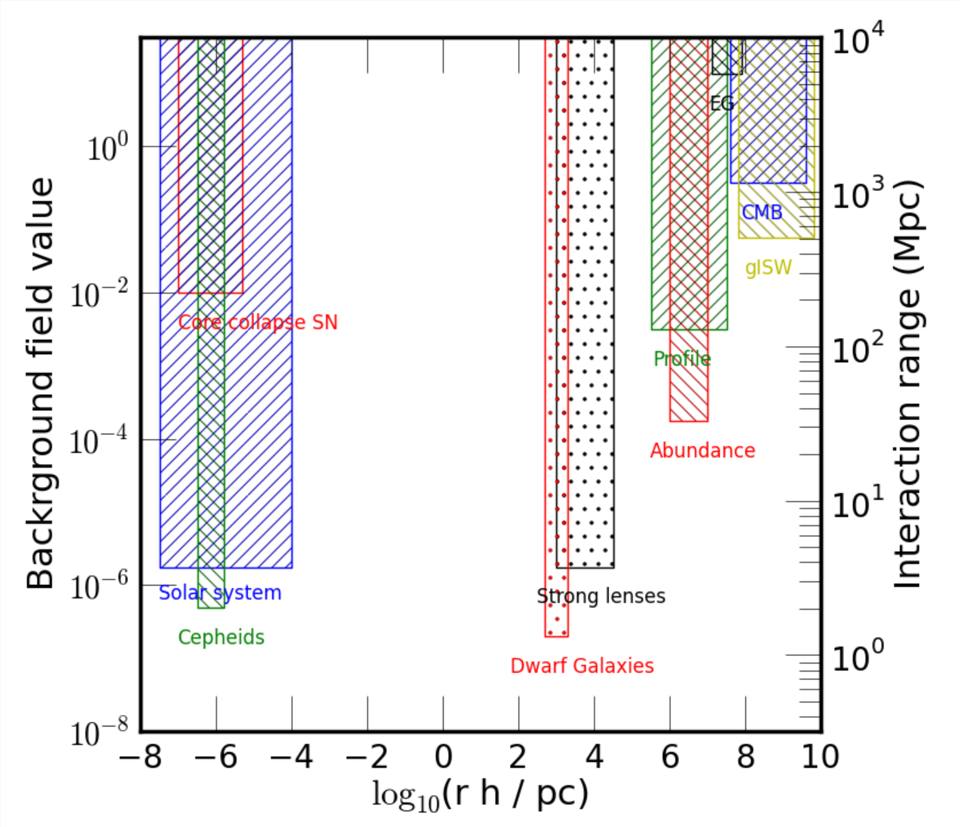


Cosmological tests of gravity



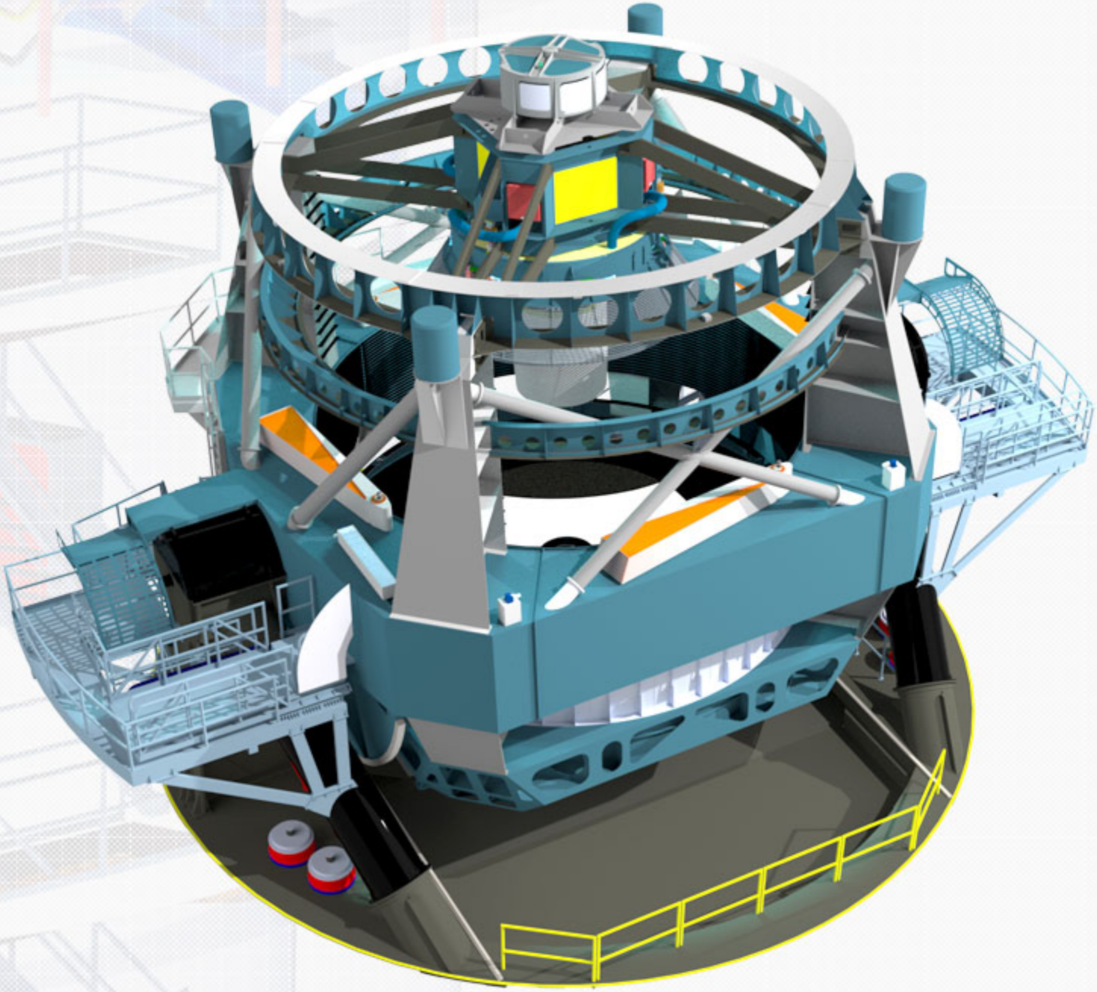
- 1st level of tests: compare growth of structure and geometry.
- 2nd level of tests: compare dynamics and lensing measures of structure.
- LSST will enable multiple tests of both levels, e.g. it will provide the lensing information on *all* regimes over five decades in length scales (see above).

Astrophysical tests of gravity

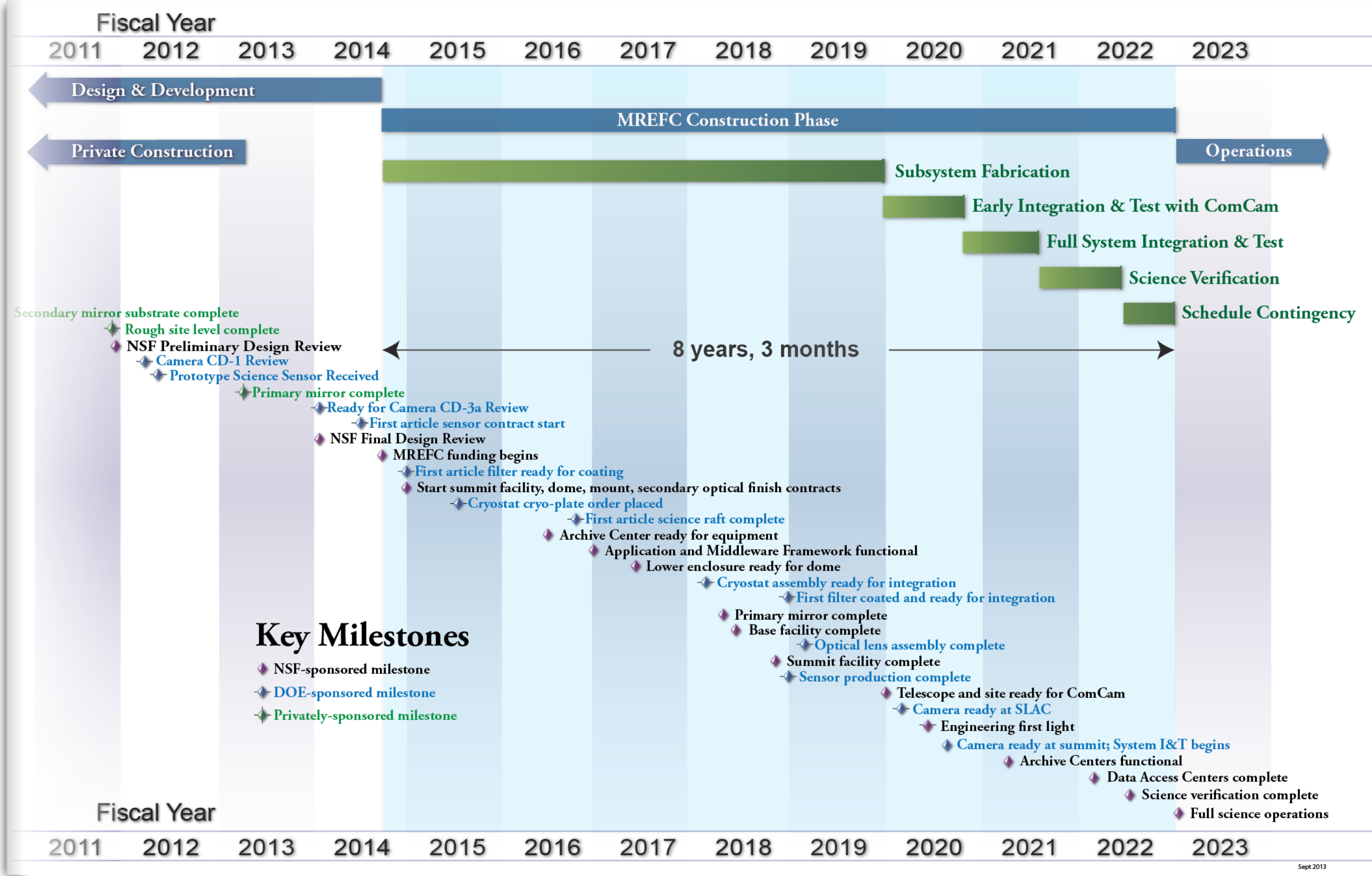


- Recent work has opened a new avenue to testing cosmologically motivated gravity theories: the nearby universe! The figure shows progress on testing chameleon theories of gravity.
- LSST will provide imaging and variability of ~all relevant stars and galaxies, although these are not cosmological objects in any conventional sense.
- See Snowmass report on Novel Probes of Gravity and Dark Energy

The path to first light



Integrated Project Schedule for Baseline Plan



LSST Dark Energy Science Collaboration

- The Dark Energy Science Collaboration was formed in June 2012 to prepare for and carry out cosmological analyses with LSST data
- DESC White Paper: arXiv:1211.0310
- Sixteen Working Groups are working on a set of ~50 tasks for the first phase, extending to 2015.

- Analysis Working Groups **Jeff Newman**
  1. Weak Lensing — Michael Jarvis, Rachel Mandelbaum
  2. Large Scale Structure — Eric Gawiser, Shirley Ho
  3. Supernovae — Alex Kim, Michael Wood-Vasey
  4. Clusters — Steve Allen, Ian Dell'Antonio
  5. Strong Lensing — Phil Marshall
  6. Combined Probes, Theory — Rachel Bean, Hu Zhan
  7. Photo-z Calibration — Jeff Newman (acting)
  8. Analysis-Computing Liaison — Rick Kessler
- Computing and Simulation Working Groups **Andy Connolly**
  1. Cosmological Simulations — Katrin Heitmann
  2. Photon Simulator — John Peterson
  3. Computing Infrastructure — Richard Dubois
  4. Software — Scott Dodelson
- Technical Working Groups **Chris Stubbs**
  1. System Throughput — Andrew Rasmussen
  2. Image Processing Algorithms — Robert Lupton
  3. Image Quality — Chuck Claver
  4. Science Operations and Calibration — Zeljko Ivezic

How do we plan for LSST's cosmology analysis?

- To develop the high-level analysis plan and to identify the key systematics it is useful to schematically break down the dark energy analysis into the following steps.
  - Observing field/band/seeing selection and cadence issues
  - The reduction of raw images
  - The production of catalogs from the processed images
  - Measurement of statistical quantities such as power spectra
  - Cosmological analysis leading to dark energy constraints.
- Identify a set of systematics and critical algorithms that require advances by the LSST team.
- Identify simulation and computational needs to include relevant physics, test measurement algorithms and develop methodology for controlling systematics.
- The DESC white paper makes a first pass at this long-term plan and lays out the first phase of work – now in progress. The data management and simulation work is progressing in parallel.

Systematic Errors and Precursor Surveys

- LSST will need a unified and precise understanding of a set of inter-connected observables that contain *astrophysical*, *cosmological*, *atmospheric* and *instrumental* effects.
- Stage III imaging surveys – DES, KIDS, PS1, Subaru HSC – are already encountering some of these effects.
- The LSST team is developing tools and software, such as the image simulator. DESC is figuring out the applications to cosmology and synergies with ongoing surveys. Early results have shown the benefit to both sides.
- DESC plans on 6 monthly releases of products to the cosmology community via a public website. We will formalize connections with other surveys as needed, e.g. DES-LSST joint meeting planned for March 2014.
- Spectroscopic surveys such as PFS and DESI, CMB, and other experiments, have synergies at the level of cosmological effects. While collaborative work is less urgent, the ultimate scientific synergies will be valuable.
- Space based surveys, Euclid and WFIRST, have important synergies as well.

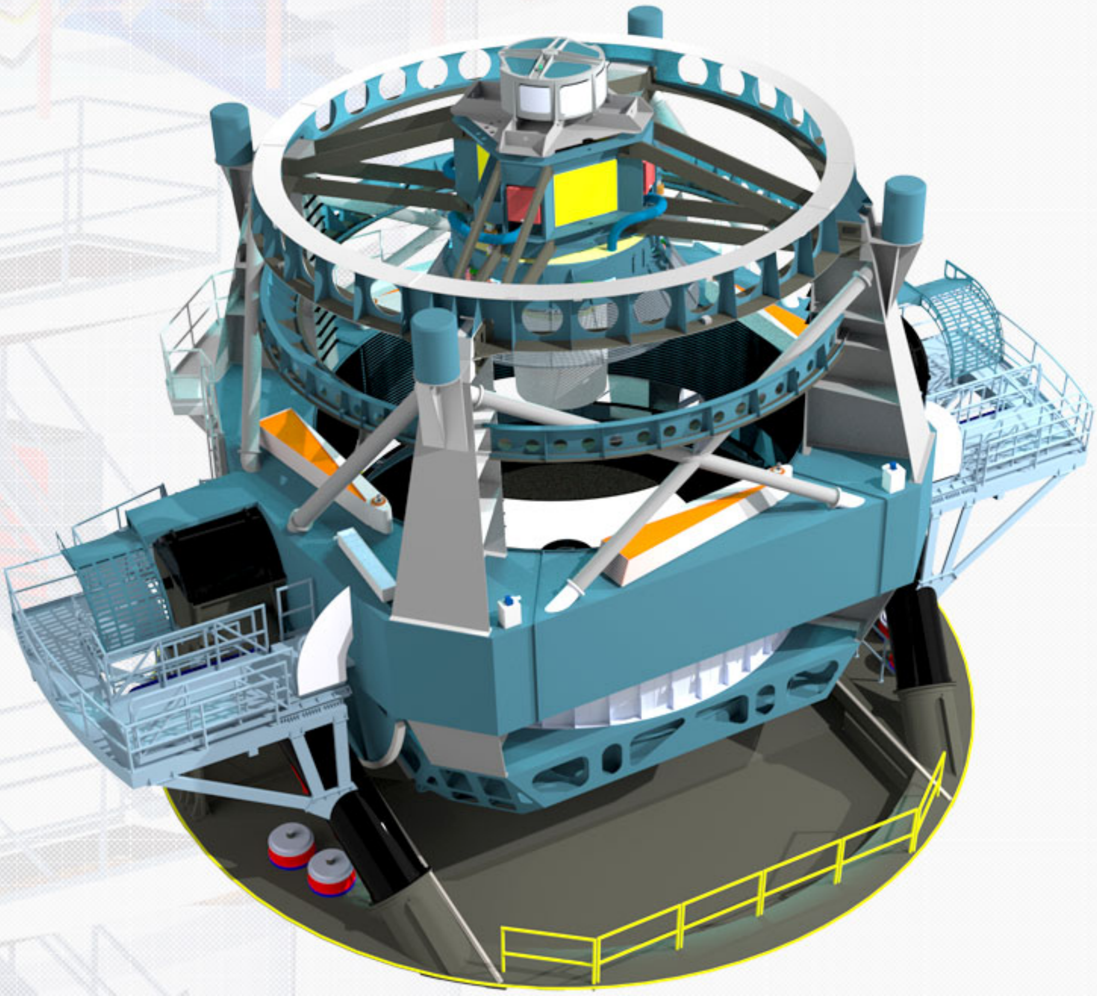
Summary and Conclusions

- LSST is on course to be the next generation cosmology survey with multiple probes of dark energy.

- We are preparing an integrated system that will cross-calibrate a diverse set of measurements and deliver on LSST's capability to measuring the properties of dark energy and other aspects of fundamental physics.

- Our preparations are not occurring in isolation: we have begun synergistic interactions with precursor imaging surveys. We expect to contribute to and learn from the progress in cosmology between now and LSST's first light.

Spare Slides/Q&A



Dark Energy Probes: Systematics

A few examples to illustrate the nature of systematics and uncertainties in going from pixels to dark energy:

- The starting point in analyzing an imaging survey, the identification of stars and galaxies, can introduce a number of subtle systematic errors.
  - How does one distinguish a star from a galaxy?
  - Where does one demarcate the boundary of a galaxy or the boundary between two overlapping galaxies?
- Next: measure galaxy shapes and infer the masses of galaxies & clusters.
  - The measurement of galaxy shapes, corrected for the effects of the Point Spread Function (PSF) of the atmosphere and telescope, is linked to a second set of systematic errors.
  - The relation of galaxies or clusters to their host halo masses is subject to astrophysical uncertainties and requires multi-wavelength data (for clusters).
- Correlations of galaxy shapes, sizes and positions + Likelihood analysis leads to dark energy constraints.
  - Sources of spurious correlations (physical, algorithmic and instrumental) masquerade as signal
  - Photometric redshift errors can obscure the tomographic signatures of dark energy
  - How should we choose "nuisance" parameters to fit for systematics: thousands or dozens?

Systematic Errors: Overview of WL I

Lensing->cosmology pipeline:

1. Object detection and star-galaxy classification
2. PSF (point spread function) measurement from stars
3. PSF interpolation onto galaxy positions
4. Galaxy shape measurement and PSF deconvolution (or equivalent)
5. Measurements of shear correlations and covariances
6. Tomography (redshift binning) and inference of cosmological parameters

Systematic errors that can enter into the various steps of the lensing->cosmology pipeline:

- Theory uncertainty/high ℓ information
- Intrinsic alignments
- Photo-z calibration
- Shear calibration
- PSF correction

Systematic Errors: Overview of WL II

- For cosmological applications, essentially all lensing systematics may be classified as one of three kinds:

  1. Additive, 2. Multiplicative, 3. Redshift errors

$$\hat{\gamma}(z_s) = \gamma(z_s + \underset{3}{\delta z})\left[1 + \underset{2}{\zeta}(z_s)\right] + \underset{1}{\gamma_{sys}}(z_s)$$

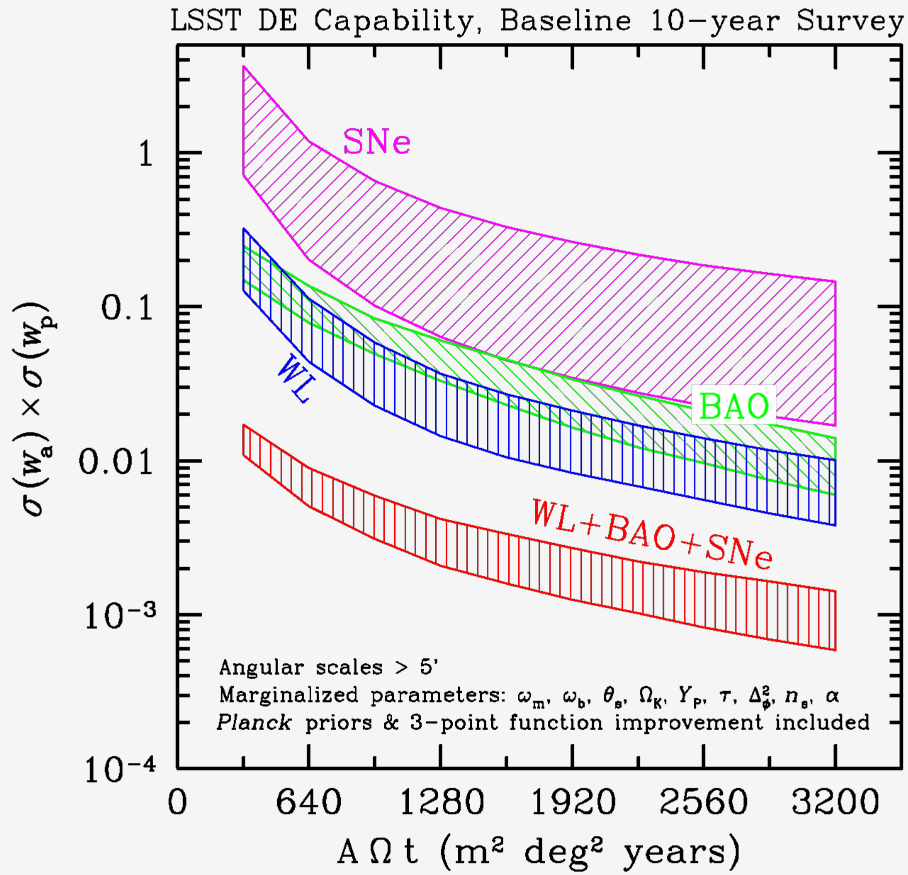
- Intrinsic alignment errors (1)
  - Linear alignment model. Recent bounds from data (SDSS/MegaZ) are useful but better measurements from Stage III surveys will help.
- Shear calibration (2):
  - With simulated images can get sub-percent performance in high S/N regime.
  - Ongoing work on algorithms aimed at LSST requirements: ~0.002 level calibration.
- PSF correction (1) (also connected to shear calibration)
  - Telescope and active optics designed to reduce coherent PSF anisotropy
  - Multiple exposures help reduce PSF from stochastic sources - atmosphere etc.
  - PCA based interpolation corrects non-stochastic sources and improves with survey size
- Spectroscopic calibration of photo-z's (3)
  - Photo-z's are characterized by scatter and bias. Bias required to be controlled at the ~0.003 level for LSST.
  - Calibration by spectroscopic redshifts made easier by cross-correlation methods.

Systematic Errors: Overview of WL III

Sources of systematic errors	Nature of advance
▪Theoretical prediction	Nonlinear modeling. Gas physics?
▪Intrinsic Alignments	Need better constraints from data. Self-calibrates but with significant degradation.
▪Source redshift distribution	Spectroscopic data and techniques
▪Shear calibration	Algorithm driven. Partially self-calibrates.
▪PSF anisotropy	Telescope design & performance. Atmosphere/stochastic contribution reduced by large number of exposures
▪Interpolation of PSF	Algorithm development. PCA approach already scales with survey size.

Note: For systematics like PSF correction, current datasize (few million galaxies) limits tests of systematic correction schemes. Expect at least an order of magnitude improvements with Stage III surveys.

DETF FoM(t) during ten year survey



Forecasts are sensitive to assumptions about systematic errors.